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THREE-DIMENSIONAL MODELLING OF THE TERRA NOVA BAY SEA FLOOR (ROSS SEA - ANTARCTICA)

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Abstract

The importance of gathering data on the Antarctic coastline and its adjacent waters has been widely recognised by the Antarctic Treaty Consultative Meeting (ATCM), the Council of Managers of National Antarctic Programs (COMNAP) and the Scientific Committee on Antarctic Research (SCAR). In particular, both for navigational safety and environmental monitoring, it is very desirable to increase hydrographic activity in those areas which have the most significant importance from a scientific or navigational point of view - such as in the continental shelf and continental slope areas of the western part of the Ross Sea.

Quite apart from the safety of navigation requirements, knowledge of the seabed topography is necessary to study and understand the various phenomena taking place in the marine environment. For example, the movement of water masses and their mixing processes depend on the shape of the seabed and adjacent coastline. The sea area surrounding Antarctica is one of the least explored parts of the world's oceans and the available bathymetric data is only sufficient to allow a very general analysis to be made.

With the probable growth of tourism and fishing around Antarctica and with the increasing need to understand the effects on the world's climate of Antarctic water patterns, it is necessary to consider powerful new techniques - such as three-dimensional modelling of the sea floors - in order to build up more quickly an effective and reliable bathymetric data base of Antarctic waters.

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1. INTRODUCTION

The need for increased research to define the coastline of the Antarctic continent and to chart its adjacent waters has been recognised as of primary importance [3] in view of its significant influence with respect to navigational safety and to the protection of the unique environment of Antarctica. Knowledge of the seabed topography is of vital importance to the study and understanding of the various phenomena which occur in the marine environment. For example, the movement of water masses and their internal mixing patterns are largely dependent on the morphological characteristics of the seabed and adjacent coastline. The aim of this paper is to show how computer-aided methods could improve and speed-up the analysis of bathymetric and oceanographic data.

For many years, experts in various different fields have used spatial data handling in their applied research. On land, Geographical Information System (GIS) have already been invaluable in the automation of traditional cartographic procedures and in the centralized management of data, such as in environmental monitoring and in cadastral applications, etc.

Both in the case of terrain and sea floors, the peculiarity of the problem resides in the huge amount of data needed to represent natural phenomena, in the heterogeneity of applications and measures, and, finally, in the necessity of efficient tools for coding, handling and retrieving information. In this sense, a good starting point is represented by a valid model for the physical environment or sea floor, model which somehow represents the part of information which is common and sharable among specific application contexts [WEIBEL and HELLER 1990, FALCIDIENO et al. 1992].

The majority of traditional models used in commercial GIS are not suitable for the specific context of bathymetric data coding and modelling. The sea floor samplings are usually made in critical environmental situations, and the presence of ice prevents an exhaustive coverage of the sea floors. Moreover, the sampling is carried out according to rules corresponding more to the safety of navigation and to cartographic purposes than to the requirements of a high fidelity sea floor modelling. The straightforward use of typical GIS techniques, for example computing of regular grids with interpolation techniques, might give acceptable results from an aesthetic point of view. Three-dimensional modelling is often simply used for data presentation, while a good three-dimensional model has to be constructed according to the two following general criteria: on the one side, it should limit the occurrence of approximation errors, on the other side it should exploit all the information either explicitly or implicitly contained in the data (e.g. features which can be deduced by *a priori* analysis of the data set) [FALCIDIENO et al. 1996].

[3] XIXth A.T.C.M. (Seoul 1995) recommended (Resolution 1-1995) that priority should be given to hydrographic surveys and nautical charting activities, and that these should be coordinated by the International Hydrographic Organization (IHO).

This paper explains the approach which has been developed by a group within the Italian National Antarctic Research Programme (PNRA) to represent part of the Antarctic seabed. The approach is based on the following main steps: analysis of measured profiles of the sea floors for discarding redundant data and for extracting characteristic points (i.e. peaks and pits); definition of a morphological skeleton of the sea floor, through an analysis of the profiles which highlights the ridges or the canyons of the sea floor; construction of the final sea floor model as a triangulation constrained to the recognized characteristic lines.

What follows is an evaluation of the research activity carried out by the PNRA and a presentation of some of the results, obtained at the NRC Institute of Applied Mathematics, by the three-dimensional modelling of part of the Antarctic seabed using the irregularly distributed data collected by the Italian Navy Hydrographic Institute during their recent Antarctic expeditions.

2. ITALIAN CONTRIBUTION TO THE MARINE ANTARCTIC CARTOGRAPHIC DEVELOPMENT

During the last two decades, there has been a rapid and constant increase in hydrographic activity in the Antarctic sea area which has provided almost entirely new information on the shape, nature and structure of the seabed. This information has been included in a chart of the GEBCO series, scale 1:6,000,000, edited by the International Oceanographic Commission (IOC) and the International Hydrographic Organization (IHO) (GEBCO, 1980).

However, in spite of the increasing amount of human, instrumental and financial resources which have been devoted recently to bathymetric surveys in the area - using the most advanced and sophisticated systems of radio positioning and sounding - our general knowledge of the Antarctic sea floors is still far from being complete, especially with respect to the delineation of the coastline and inshore bathymetry. This is mainly due to the almost constant presence of ice - both fixed and mobile - which makes all coastal hydrographic activities extremely difficult for most of the southern summer and even more so in winter.

Antarctica has a very long coastline, roughly 35,000 km. Of this, only 17% is true coast in the sense of exposed rocks or beaches. The remainder is formed either of a floating ice-shelf (45%) or rocky coast with ice (38%).

The unique characteristic of Antarctica is its continental shelf. Whereas other continental shelves extend to a depth of 200 metres, the one surrounding Antarctica extend to an average depth of 460 metres. In some cases, depths of up to 500 - 600 metres are frequent and, in the Ross Sea, the shelf extends to even greater depths (800 m). This situation is possibly an isostatic reaction to the enormous weight of ice on the continent during the last ice-age.

In general, the Antarctic continental shelf varies greatly in width and it is unusually narrow, in some places where it is a few miles wide and in others, it seems to be almost non-existent. The overall area of the Antarctic continental shelf is 2.3 x 10^6 km^2; roughly 4-5 times that of the North Sea; all of it is in the seasonal pack-ice zone.

These facts illustrate the enormous problems - both organizational and logistic - which face any gathering of bathymetric and coastal data in Antarctica. In order to improve the situation, a coordinated, continuous, collaborated effort, at international level, is required, in order to allow a full scientific investigation of the area.

It was precisely with this objective that, in 1992, a "Permanent Working Group for Cooperation in Antarctica" (PWGCA) was formed within the IHO to carry out the following tasks:

(1) to plan the work of the small scale International Charts of Antarctica;
(2) to examine and evaluate the state and quality of the hydrographic surveys already carried out or being carried out;
(3) to develop and encourage every type of cooperation in the hydrographic field by maintaining appropriate connections with SCAR, IOC and COMNAP.

In 1986, Italy started a programme of Antarctic coastal and bathymetric surveys in the sea area adjacent to the Italian base, "Terra Nova Bay Station". The area had a coastline of about 140 km and a sea area of about 2,400 km^2, partly covered with ice. The aim was to produce two bathymetric charts, one covering the whole area at scale 1:100,000 and a coastal chart at scale 1:50,000. Topographic and bathymetric surveys were carried out (and mostly completed) by the Italian Navy Hydrographic Institute during expeditions in 1986/87, 1987/88 and 1989/90. During the topographic surveys, some geodetic stations were set up, using GPS Magnavox 1601 satellite receivers with relative positional accuracy ±3 m; these were later connected using an AGA 140H Total Station by Geotronics (extreme range 7 000 m., precision ±5 mm.). At some stations, Motorola Miniranger radio-navigation transponders were installed. Ship positioning was obtained by the Motorola Falcon IV Surveyor system and depths were obtained using the ultrasound Raytheon DSF 6000 (frequency 33-210 kHz, extreme depth 6,000 m, precision ±3% of the depth).

A rigid inflatable boat (9 m long) and an aluminium boat (16 m) were used in inshore areas; both boats were fitted with some positioning and depth finding equipment as of the type mentioned above. In the 1987/88 expedition only, a larger vessel (MV POLAR QUEEN) was also available.

In order to try to determine the depths in an area of about 8 km^2, covered with ice (Thetis Cove), an attempt was made, during the 1989/90 expedition, to use the Datasonic SBP 5000 low frequency (3.5 - 7.0 kHz) transducers, mounted on a special sledge pulled across the ice by a crawler tractor, fitted with a Motorola Falcon IV Surveyor system. Unfortunately, this sounding method was not as successful as had been hoped since the depth recording was very confused and almost illegible due to the reverberations undergone by the ultrasonic impulse through the ice layer. Thetis Cove was therefore surveyed by immersing a portable ultrasound transducer through 86 holes made in the ice, 250 m apart, on a regular grid pattern established using the Total Station System.

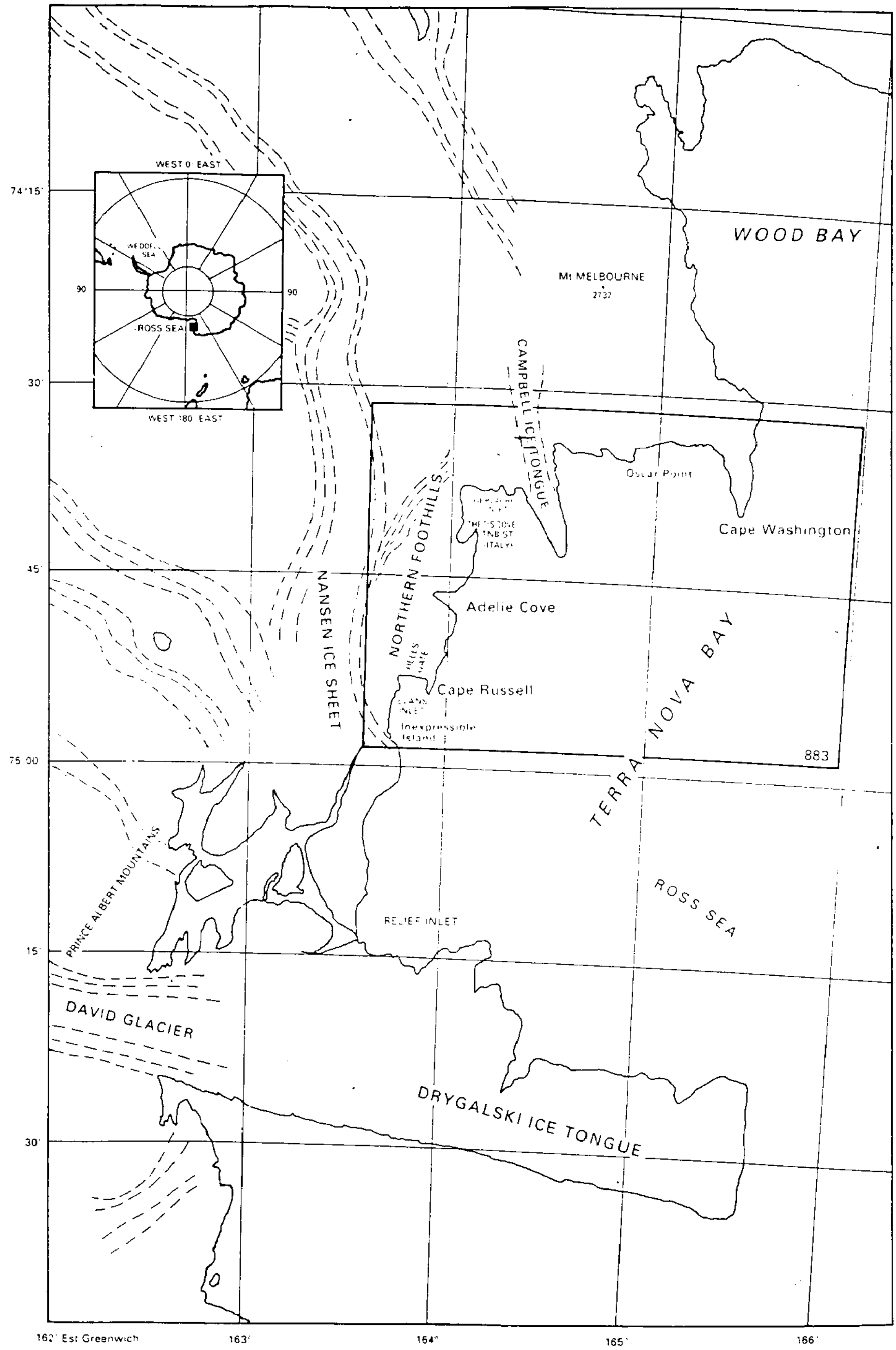

FIG. 1.- Study Area (within the limits of Italian Chart No. 883).

The bathymetric data collected during the three expeditions has been used to publish two new Italian charts - No. 882, scale 1:50,000 and 883, scale 1:100,000 (Italian Hydrographic Institute, 1989, 1991). A new programme of topographic and bathymetric surveys was undertaken by the Italian Navy Hydrographic Institute's expeditions with the objectives of gradually extending the area previously explored and of publishing a new chart at a scale of 1:500,000 of the approaches to the Italian Terra Nova Bay Station.

3. MORPHOLOGICAL AND BATHYMETRIC FEATURES OF TERRA NOVA BAY

Before describing the procedures and calculation methods which have led to the three-dimensional modelling of the sea areas surveyed during the course of the above mentioned expeditions, it is appropriate to comment on the general features in the area of the study which lies entirely in the area covered by Italian Chart 883 in the northern part of the large inlet known as Terra Nova Bay which is about 60 miles wide (North to South) and 30 miles deep and lies on the central, western, side of the Ross Sea (Fig. 1).

The Bay lies between 74°35'S and 75°15'S and extends from the coastline to about 165°30'E. It is bound on the north by the southernmost extremity of the Mount Melbourne (a 2,732 m high volcano which is, at present, in a quiescent state) and, on the south, by the northern border of the Drygalski Ice Tongue [4] (One of the most extensive outfall glaciers which characterize Terra Nova Bay) which stretches, as a floating ice mass, for about 60 miles eastwards from the coast.

Within the area covered by Chart 883, the coastline is, for the most part, rocky with high, wave-cut, cliffs with numerous deep inlets (Thetis Cove, Adelie Cove, Evans Cove, Gerlache Inlet) in which the sea ice persists until well into the summer season (mid-January to mid-February), especially in Evans Cove and Gerlache Inlet. The large area between the Campbell Ice Tongue [5] and Cape Washington differs from the usual regular and cyclical seasonal behaviour of the coastal ice as this remains much later in the season than anywhere else and presents a wide coastal zone with all of the typical characteristics of fast-ice and only at its outer edge - most exposed to the breaking up action of wind and waves - does the ice tend to break up to expose areas of waters. This fact has prevented the completion of the bathymetric surveys of this sections except for a small strip close to the eastern edge of the Campbell Ice Tongue. The sea bed is relatively deep with depths of 500-600 m only a few miles offshore. In the north-western area, there is a submarine plateau characterized, in its central part, by a very irregular pattern, apparently engraved by a series of canyons of

[4] In December 1995 a new position of the D.I.T. front (as reported in Fig. 1) localized at 75°30'41.22"E-165°38'20.16" (in January 1995: 75°30'41.4"S-165°37'05.4"E) was determined using the GPS TRIMBLE 4000 receiver.

[5] In February 1996, a new position of the C.I.T. front localized at 74°43'09.24"S-164°33'11.76"E was determined using the GPS TRIMBLE 4000 receiver.

which the main one penetrates with its head fronting the Gerlache Inlet and with its axis running northwest/south east and with depths from 400 to 500 m.

Between the site of the Italian Station, close to the narrowest part of the entrance to Gerlache Inlet and Cape Russel, the 100 m depth contour runs parallel to the coast. In the minor inlets, there are depth from 40-70 m (Adelie Cove) to about 250 m (Thetis Cove) and 700 m (Evans Cove). The fact that there are such great depths in Evans Cove, suggest that the sea has cut underneath the glacier (Hells Gate) which forms the northern side of the cove. This has been confirmed by recent (1995) geophysical investigations.

In the south-eastern area, the seabed slopes smoothly and uniformly, with the depth contours running at 045°/225°, and with maximum depths of 900-1100 m.

4. THREE-DIMENSIONAL MODELLING OF THE SEA FLOOR

There is no doubt that nautical cartography is indispensable for navigation safety and for operations taking place at sea. However, the growing sophistication of computerized techniques available today enables three-dimensional models of the sea floor to be produced and these open up new perspectives which are better than the traditional cartographic procedures. The limitations of purely two-dimensional portrayal of the data can, in fact, be overcome very easily by taking advantage of the results obtained in other areas, in particular the Geometric Modelling and Computer Graphics.

Together with the traditional cartographic output, indeed, the construction of effective and three-dimensional digital models of the sea floors is highly desirable, which can be defined as the computational structures supporting the reconstruction of the whole sea floors starting from the measured points. The digital model has a two-fold purpose: it gives a method to approximate the real surface where data are missing, and it suggests a logical structure for coding all the measures that have been collected. Moreover, based on a high quality digital model of the sea floor, several cartographic operation could also be automated, as in the case of terrain in GIS.

In other words, the capacity of three-dimensional modelling must not be limited to obtain a good and realistic visualization, but rather it must offer new hints and ideas for high level activities which could be performed in an almost automatic way through computerized modelling. For example, the track of a submerged robot could be planned or the movement of water masses in coastal waters could be studied more easily and effectively by researchers.

Natural land surface modelling has been a topic of research for several years. However, the typical techniques of the land-based discipline cannot be applied directly to the Antarctic marine field. For a start, the spatial distribution of the available data is very irregular and unbalanced. Normal bathymetric data is acquired according to the guidelines in "IHO STANDARD FOR HYDROGRAPHIC SURVEYS", parallel lines of soundings are run at intervals apart depending on the anticipated depth and importance of the area. Using a traditional echo-sounder, the sampling is very dense and uniformly distributed along the track of the sounding vessel but there are gaps of unsounded areas between the tracks. Modern multibeam systems overcome this problem to some extent but the presence of ice results in further gaps in the available data.

Regular grids are inappropriate in this case, because the interpolation of the surface at the grid vertices would be heavily influenced by the irregular distribution of the points. Models based on the triangulation of the data are much more suitable for irregular distribution and are defined as a set of triangular facets whose vertices are the measured points. Another great advantage of triangulation models is the ease of model updating: for instance, if new points have become available as a result of new expeditions, the introduction of these points in a grid-based model requires the entire grid vertices being computed again, while a model based on the triangulation requires only local operations on the model. In essence, the new points have to be located within existing triangles and only these triangles have to be split, so as to generate new smaller triangles with the new points as vertices.

Although triangulation gives a good representation of the sea floors, the presence of very dense data along profiles rather far apart, generates long and narrow triangles even when techniques are adopted to minimize this effect, such as the Delaunay triangulation [DELAUNAY 1928]. The stairway effect produced by these long and narrow triangles may distort the graphic representation, and cause the model itself to be unnecessarily cumbersome. For these reasons, the modelling phase was preceded by a careful analysis of the sounding profiles in order to eliminate, from the profiles, all those points which did not contribute significantly to the shape of the profile itself (generalization). This phase of the analysis also allowed the identification of characteristic points of the profile, that is those points with the maximum information content. Furthermore, because the sound profiles can be assimilated, at least to a first approximation, to vertical sections of the sea floor, it is possible to extract additional information on the morphology of the sea floor through the identification of characteristic points of the profiles which suggest the presence of characteristic features of the sea floor itself, such as for instance ridge lines or canyons. After this data analysis phase, it is possible to build a true model of the sea floor which will perfectly reflect the characteristics found.

The extraction of morphological characteristics, performed directly on the original data and then inserted in the construction of the model, represents the fundamental element that distinguishes our approach from traditional modelling methods. In fact, even if adaptable, the Delaunay triangulation, being based on equiangular properties of the triangles which make it up, imposes on the data a structure which might be different from the actual surface shape, by substantially eliminating or modifying the characteristic lines of the surface, such as ridge or canyon lines.

The proposed approach, as simplified in Figure 2, is therefore made up of the following steps:

- simplification of the profiles in a manner directed by the shape and extraction of their characteristics points;

- identification of the surface characteristic lines, such as ridges and canyons, by observing the morphological resemblance among adjacent profiles;

- construction of the triangulation constrained by the selected characteristics of the surface.

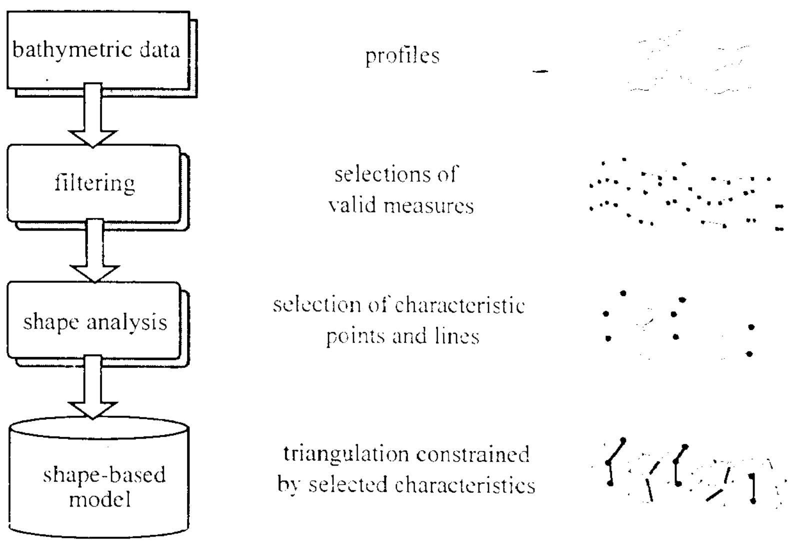

FIG. 2.- Different phases of the sea floor modelling process.

The various phases of the approach used will be treated in greater details in the following sections; the results of the reconstruction of the three-dimensional model of the sea floor of the sea area under study, as reported in the above mentioned Chart 883, will also be given.

4.1 Simplification of the profiles as directed by the shape

The simplification procedure is well-known in cartography as generalization, or caricature, and is, for example, applied to the simplification of coast or contour lines. In this specific field various generalization methods have been suggested during the course of the years and some authors have suggested schemes for the evaluation of the "goodness" of the various approaches. For example, the method defined by Douglas and Peucker [DOUGLAS and PEUCKER 1973] has been judged as the "most cartographically valid" in the sense that it produces the least vectorial displacement of the original line and it better preserves the angularity of the original line. In short, the basic idea of this method is that of the tolerance band: once having chosen a portion of the line to simplify, a tolerance band is defined by considering an offset of the segment joining the extreme points of the line portion. If all the other points fall within the band, they can be eliminated without loss of information, and the portion of the line can be represented by the segment between the extreme points. The application of this algorithm produces good approximation results but is strongly dependent on the orientation of the band with the consequence that the generalization of a line can be different depending on the starting point of the procedure [ORGOLESU 1994].

To overcome these problems the generalization problem has been considered by following a technique similar to that used in the analysis of the signal, that is, an attempt has been made to resolve each sound profile in a series of lines which represent it at different scales, just like a signal can be resolved into its different frequencies. In particular, the wavelet transformation technique has been adopted [DAUBECHIS 1992, MALLAT and HWANG 1992] with which it is possible to obtain a multi resolution analysis, that is, at each step of the simplification, the non significant details at that scale are distinguished from the main characteristics. In this manner, the points giving a greater contribution are recognizable in that these are exactly the ones which are left in the last resolution step with the wavelet transformation, while the importance of a certain detail can easily be tied to the level at which this detail disappears in the transformation. Figure 3 shows an application example of the wavelet transformation of a profile: the points which remain in the fourth simplification step (see Fig. 3d) correspond to the overall characteristic points of the profile.

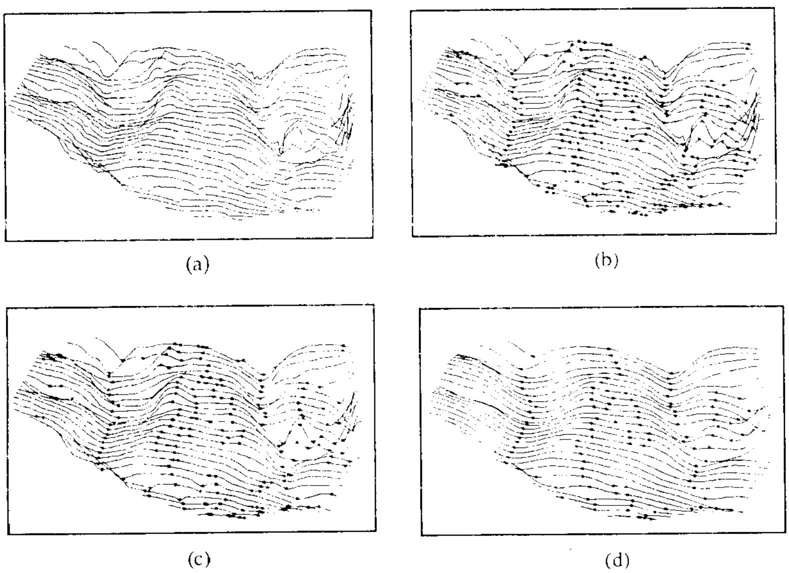

FIG. 3.- Simplification of the profiles with the wavelet transformation: (a) (b) (c) (d) simplification steps.

4.2 Recognizing surface characteristics

After simplification and characterization of the profiles, the second step involves the extraction of additional information on the sea floor morphology through the identification of shape similarity between adjacent profiles that might suggest the presence of some morphological characteristisc of the sea floor itself, as for instance ridge or canyon line [ORGOLESU 1994]. Because ridges and canyons can be seen as lines formed respectively by local maximum and minimum points, it will be sufficient to search for similarities between maximum and minimum points recognized on the profiles. Having fixed a starting point on a given profile, a point with similar morphology and reasonably close to the starting point is located on the adjacent profile; to each starting point for the search is associated a cone of influence which selects a portion of the profile adjacent to the point, inside which the following characteristic point can be searched.

The concept is illustrated in Figure 4, where point P represents the current point from which the search initiates with its associated cone of influence. The axis of the cone is oriented in the direction of the possible characteristic line segment identified with the previous step. If inside the cone there are some candidate points to be connected to P, like points Q1 and Q2 in the figure, then a morphologically more similar point is selected among these, that is that point which presents curvature values closer to P.

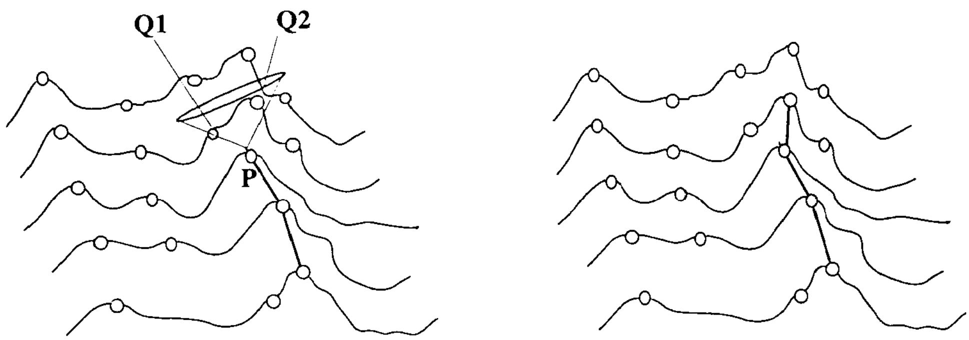

FIG. 4.- Selection of similar points between adjacent profiles.

4.3 Triangulation constrained by surface characteristics

The characteristics that have been thus extracted generate a morphological structure on which the three-dimensional model of the sea floor is constructed and is defined as a triangulation constrained by the characteristics themselves [FALCIDIENO *et al* 1992]. A triangulation constrained by a set of segments is a triangulation in which the constraints are forced to be sides of triangles, so that possible optimization criteria of the triangulation cannot alter the configuration of the constraints. The constrained triangulation is the computerized structure with the best properties with respect to the requisites imposed by the particular context: because the characteristic points and lines are explicitly codified, the model approximates well the set of data; the insertion of new points or constraints can be accomplished efficiently and with only local modifications to the structure. An example of the procedure is shown in Figure 5: the morphological characteristics extracted from the profiles are illustrated in (a) and the three-dimensional model obtained with the Delaunay triangulation constrained by the characteristics is shown in (b).

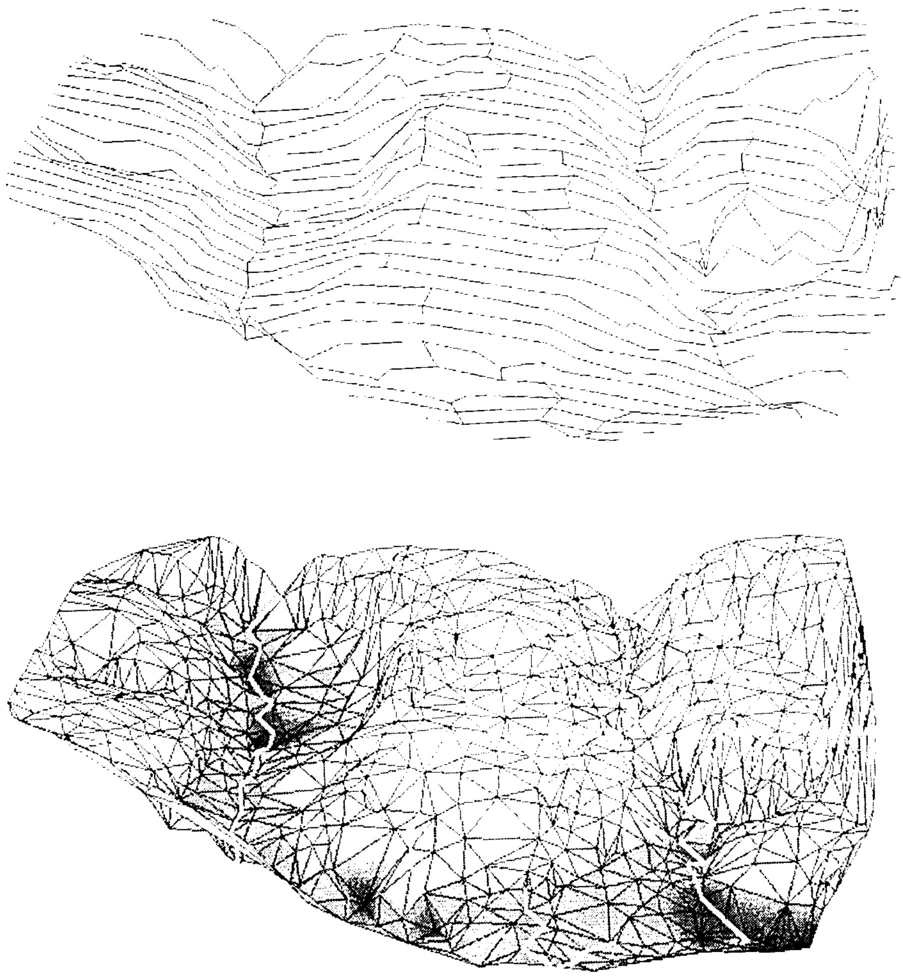

FIG. 5.- The final phases in the construction of the three-dimensional model of the sea floors:
(a) characteristic lines of the surfaces as extracted from the profiles;
(b) Delaunay triangulation constrained by the extracted characteristics.

Even though the Delaunay triangulation is considered a standard for the representation of surfaces, optimization criteria different from that of equal angles have been studied recently, using criteria which are better suited to adjusting to the shape of the surface [DYN *et al* 1990].

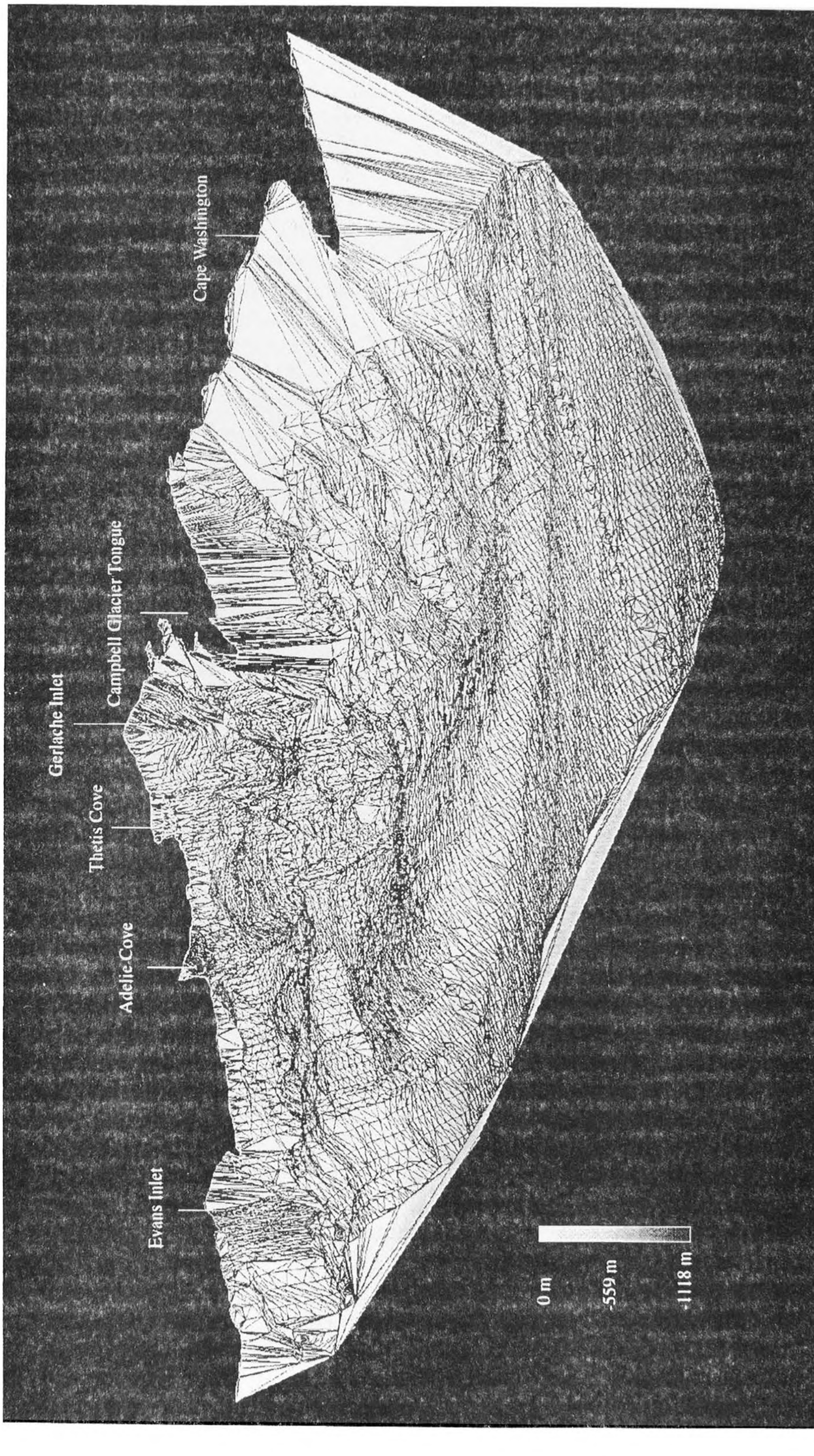

FIG. 6.- Three-dimensional modelling of sea floor relative to Chart No. 883.

4.4 Results

With this procedure it is therefore possible to obtain a reconstruction of the surface based on its shape by carrying out a geometric reasoning on the acquired data so as to delineate a morphological structure on which it is possible to construct the final surface model.

Figure 6 reports the three-dimensional modelling of the sea floor of Terra Nova Bay area as described in paragraph 3. The three-dimensional model has been obtained by processing the data acquired during the expeditions in Antarctica carried out by the Hydrographic Institute of the Italian Navy except the last one in 1995-96, according to the procedure described above and it is represented by a constrained Delaunay triangulation made up of about 20,000 points. Such points present a non homogeneous distribution, due both to the morphology of the sea floor (in flat areas the initial sampling contained redundant information which the simplification process eliminate) and to the different sampling step adopted in the data acquisition phase depending on the distance from the coast (more dense near the coast and less dense in the open sea).

It is appropriate to remember in fact that the modelling shown in Figure 6 refers to the sea area contained in Chart 883 at a scale of 1:100,000 whose boundaries are shown in Figure 1. However, this chart also includes Chart 882 at a scale of 1:50,000 which has been processed using a greater number of sounding data, as it is on a different working scale.

The marine area covered by Chart 882 appears in the modelling slightly darker than the surrounding areas; this would seem to indicate, on the basis of the chromatic scale of the depths used, that it is composed of shallower sea floors. In reality, the more intense colour is only a sign of greater density of the sounding data.

Furthermore, it is possible to see how the model presents very extended triangles along the coastal strip in the proximity of the Cape Washington promontory due to the lack of surveying in this area because of the difficulty of bathymetric investigation caused by the prolonged permanence of marine ice. In addition, the three-dimensional representation highlights those parts of coastlines composed of glaciers (Campbell Hells Gate) underneath which the sea water penetrates. In fact, these zones are formed by very long triangles placed in an almost vertical direction, a sign of the great difference in depth between the data of the coastline and the sea floor adjacent to it.

5. POTENTIAL USERS OF THREE-DIMENSIONAL SEA FLOOR MODELS

The cartographic determination and representation of sea floors have always been invaluable to any type of research at sea. There is a particular problem for such research in Antarctic waters which are seasonally covered with ice which has a significant influence on all marine life in the water column and on the seabed.

The Antarctic coastal regions - especially in the sea-ice interface layers present unique problems when it comes to setting up study models.

Terra Nova Bay has long been recognized as a marine area of prime scientific interest due to the peculiarity of its highly productive waters. These are so rich in benthic population that the international SCAR Organization (set up specifically to protect and conserve sites of specific scientific interest) recently designated a wide coastal segment of the Northern Foothills (Fig. 1) as a marine nature park. In this segment, various constraints have been laid down to safeguard the delicate ecosystem of the area without restricting certain types of research, especially marine biological research.

Since marine research requires new data even in areas where dynamic ice covering is present, it is necessary to take advantage of new techniques which can meet and solve the various obstacles to such research.

All environmental sampling, especially in extreme climatic conditions, requires appropriate instrumentation which is capable of acquiring and storing data and, if possible, of transmitting data, via satellites, to a base. For example, remote controlled or autonomous robot submarine vehicles (ROV), capable of operating in the presence or below extended, thick, ice cover. It is essential to have much better knowledge of the sea floor morphology than can be provided by traditional, two-dimensional, nautical cartography.

The use of ROVs for marine research in ice covered waters is much safer if a three-dimensional model is available before its use. Such vehicles could not operate safely -especially if autonomously operated - if they did not have in their memory storage, all available bathymetric data to reduce the risks of colliding with submerged obstacles on their pre-programmed track to their search area. At the same time, in addition to safeguarding its own safety, such a vehicle can acquire new data by comparing the memorized sketchy bathymetric data with real values obtained by its sensors.

A three-dimensional modelling such as shown in Figure 6 is equally important for the study and understanding of numerous phenomena located in the marine environment. All movements of water masses, just as the formation and mixing processes of given bodies of water are, in fact, strongly affected by the morphological characteristics of the sea floor and coastline. Therefore, the availability of a three-dimensional model of the sea floor facilitates the elaboration of mathematical models concerning the formation and evolution of such phenomena, and also the representation and mapping of particular types of ocean floors showing the structure of sediments.

Three-dimensional modelling of the sea floor can contribute effectively to provide a more realistic and immediate representation of all static or dynamic physical, chemical, biological and geological parameters that characterize a given zone with a greater adherence to the floor pattern and a better "display" of the parameters themselves, superior to a traditional bathymetric chart. Furthermore, this representation fully shows all its versatility, especially in all the research phases that require the identification of bottom sites suitable for the mooring of instrumentation chains, thus enabling the operator to use for navigational purposes not only a common nautical chart but directly the three-dimensional image of the submarine topography (as obtained from the model) provided by a monitor connected to an appropriate navigation system (for instance a GPS) in which all coordinates (x,y,z) of the sea floor have been stored.

6. CONCLUSIONS

This paper intends to show how geometric modelling techniques could be used together with traditional cartography in order to increase the knowledge of the sea floor in Antarctica. In conclusion, the following fundamental points must be highlighted:

- large amounts of data do not necessarily imply a high degree of information, and therefore a high quality of the digital model;

- a geometric reasoning on the spatial distribution of data leads to, or at least supports, the automatic delineation of important morphological features, whose presence can be explicitly coded into the model.

These aspects, which are common to other GIS contexts, are particularly important in the case of Antarctica because of the problems related to data acquisition. The proposed data analysis also may support a more efficient planning of the measurement procedures: areas almost flat could be sampled with fewer measures than rough areas. Moreover, the availability of a morphological skeleton, even if it is only partial, can give hints on the sea floor shape, also in regions where sampling is insufficient: for example, a canyon whose complete three-dimensional reconstruction cannot be performed because data are missing, due to the presence of ice. Then, if the sampled part of the canyon has been recognized into the available sea floor model, it would be reasonable to assume that the canyon continues with almost the same morphological shape than in the unsampled region, this leading to a simulated reconstruction of the missing parts. Therefore, oceanographic or biological studies could be carried out on the simulated model.

It is interesting to point out that the production of maps could also be automated, based on a high quality sea floor model, and that three-dimensional display of the sea floor could probably be much easier to understand than a map, especially for scientists who are not necessarily experts in cartography. Typical operation of computer graphics, such as visual navigation of the model, zooming utilities, translation and rotations operations, will surely help users to have a better knowledge of the sea floor topography.

The knowledge of sea floor morphology models is the basis for a series of analysis and synthesis processing of data on the area concerned. The availability of a complete and reliable model which can be updated and adhere to the original data is therefore fundamental and a starting point for every simulation algorithm in a submarine environment.

This study has presented the characteristics of interest in the Antarctica sea floor, how they can be calculated from the set of original data and finally how can they be represented them in an efficient way. In order to achieve this, a close collaboration between researchers of different fields has been necessary: geologists, oceanographers (for application), mathematicians (for modelling) and computer experts (for actual representation). This joint action from the initial planning stages of the modelling system has allowed to take into consideration the application needs imposed by the restraints of the project, from a mathematical point of view. This has provided an efficient, general and complete solution to the problem, and also has allowed to take into consideration the work of computer experts thanks to whom the conversion of these solutions into efficient structural data and algorithms has been possible.

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